Modified Atmosphere Maintains Quality of Fresh-cut Cantaloupe (*Cucumis melo* L.)

J.-H. BAI, R.A. SAFTNER, A.E. WATADA, AND Y.S. LEE

ABSTRACT: Fresh-cut cantaloupe cubes were placed in film-sealed containers in which the internal gas mixture was attained naturally (nMAP), was flushed with 4 kPa O_2 plus 10 kPa CO_2 (fMAP), or was maintained near atmospheric levels by perforating the film (PFP). While both nMAP and fMAP maintained the salable quality of melon cubes for 9 d at 5 °C, fMAP maintained quality better than nMAP. The benefit of fMAP was indicated by better color retention, and by reduced translucency, respiration rate, and microbial population compared with nMAP. Shelf life of cubes in PFP was only 5 to 7 d at 5 °C, and its rapid decline was due to tissue translucency and/or off-odor development.

Keywords: cantaloupe, fresh-cut, modified atmosphere packaging, storage quality

Introduction

FRESH-CUT CANTALOUPE (*CUCUMIS melo* L. reticulatus group) and other fresh-cut products are a rapidly growing segment of the retail and foodservice horticultural industry (Anonymous 1998). Various kinds of packaged fresh-cut melons are among the most common fresh-cut fruits available in the marketplace. While fresh-cut products have met consumers' desire for convenience, product quality and shelf life in particular are still important considerations. A shelf life of up to 10 d for fresh-cut melons is desirable in the distribution chain (Anonymous 1996), but retail stores seldom market the product for more than 3 d. Both consumers and producers would benefit from a method that would extend shelf life without adversely affecting the quality of fresh-cut products.

Fresh-cut fruits and vegetables generally are packaged in film bags or containers overwrapped with film, which creates a modified atmosphere within the package (MAP). MAP can extend the shelf life of many intact and fresh-cut horticultural products (Kader and others 1989; Gorny 1997). It can also cause the O_2 level to decrease below 1 kPa in commercial fresh-cut fruit and vegetable packages (Cameron and Smyth 1997; Qi and others 1999), which may not be desirable. A low O_2 level may retard browning and spoilage and maintain fresh appearance; however, it also can cause off-flavor and flavor loss (Cameron and Smyth 1997). A very low O_2 or an elevated CO_2 in MAP may inhibit growth of aerobic spoilage organisms, but may allow or stimulate the growth of foodborne pathogens (Farber 1991). On the other hand, growth of aerobic spoilage organisms may be considered beneficial because it warns the consumers of spoiled product. Thus, for a given product of known weight and storage temperature, proper film selection is essential for attaining a gas mixture in MAP that will maintain quality and restrict microbial growth.

The gas mixture recommended for controlled atmosphere (CA) storage of whole cantaloupe is 3 to 5 kPa O_2 and 10 to 15 kPa CO_2 (Kader 1989), and a similar gas mixture is recommended for fresh-cut cantaloupe (O'Connor-Shaw and others 1996; Portela and others 1997). With complete sanitation and meticulous laboratory care, O'Connor-Shaw and others (1996) were able to maintain a low microbial population and obtain a 28-d shelf life with fresh-cut cantaloupe held at 4.5 °C in recommended controlled atmospheres. Portela and others (1997) indicated that the recommended CO_2 concentration maintained fresh-cut cantaloupe visual quality above the limits of salability for 9 d at 10 °C and 15 d at 5 °C, and the combination of an elevated CO_2 with a lowered O_2 concentration provided additional benefit in reducing microbial counts.

A major metabolic process occurring in harvested produce is respiration. The respiration rate of produce is an excellent indicator of metabolic activity of tissue; that is, it is a useful guide to the potential storage life of the produce. Climacteric respiration, as well as the complete ripening process, indicates the end of storage life of fruit. In MAP, the equilibrium atmosphere may change rapidly to anaerobic once climacteric respiration begins.

Since the marketing period of fresh-cut fruit is relatively short, an additional benefit of MAP may be attained by actively flushing the package with the desired gas rather than allowing the MAP to develop naturally, which may take 24 h or more to equilibrate. Ayhan and Chism (1998) were able to store fresh-cut cantaloupe 15 d at 2.2 °C when the commodity was packaged in a 5 kPa O_2 and 95 kPa N_2 atmosphere; however, they did not report the gas levels present during storage. To our knowledge there are no other studies on the effect of MAP with recommended gas mixtures on the quality and microbial changes of fresh-cut cantaloupe.

We describe in this paper the quality and natural microbial population changes on fresh-cut cantaloupes when placed in film-sealed containers, where the internal gas mixture developed naturally during storage (nMAP), was rapidly attained by flushing the containers with a 4 kPa O_2 plus 10 kPa CO_2 gas mixture (fMAP), or was maintained at atmospheric levels by perforating the film (PFP).

Materials and Methods

Materials

Cantaloupes (*Cucumis melo* L. reticulatus group) of 'Athena' cv. at 3/4 to full slip maturity were harvested during July and August 1998 from a field in Maryland. The 'Athena' cv. was selected because it is being considered specifically for fresh-cut processing by Novartis Seeds, Inc. The fruit of two of the three trials were transported directly from the field to the laboratory, while the fruit of the third trial was shipped to the Philadelphia Wholesale Market, then to the laboratory. Thus, the fruit of the latter trial was in transit about two d before being available for experimentation. All fruit was kept overnight at 5 °C prior to processing on the following morning.

For each trial, 15 cantaloupes of about 2500 g each were washed with water at 5 °C and dipped in sanitizer (200 µL L^{-1} sodium hypochlorite solution, pH 6.5) at 5 °C for 2 min. The sanitized fruit were peeled, dipped in the same sanitizer for 30 s, halved, cored, sliced, and cut into 2 cm-square cubes. The cubes were rinsed in 150 µL L^{-1} sodium hypochlorite solution for 30 s and allowed to drain at 5 °C for 1 h, then separated into three groups, representing three replicates. Each replicate was divided into 31 uniform samples (175 g) for 3 package treatments, 2 temperature treatments, and 6 sampling times.

The cantaloupe cubes were placed in a 1-liter plastic container underlaid with a Fresh R Pax ™ water-absorbent pouch (Maxwell Chase Technologies, Atlanta, Ga., U.S.A.). The container was thermo-conglutinated with the LDX-5406 film (Cryovac, Duncan, S.C., U.S.A.) using a food pack machine (Model FP Basic V/G; Ilpra, Italy). The oxygen transmission rates (OTR) of the film were 1006 and 1448 mL m^{-2} 24 h^{-1} atm^{-1}, at 2.5 °C and 5 °C, respectively. The packages were divided into 3 groups for the following: (1) the packages were allowed to naturally form a modified atmosphere (nMAP), (2) the internal atmosphere of the packages was flushed with a gas mixture of 4 kPa O_2 plus 10 kPa CO_2 (fMAP), and (3) the film was perforated with a needle to have 10 1.5-mm holes (PFP). The two temperature treatments were 5 °C continuous, or 2 d at 2.5 °C and then transferred to 5 °C. The latter was to simulate the processing and marketing temperature conditions, respectively. Samples were removed on 0, 2, 5, 7, 9, or 12 d for analyses of gas composition, quality, and natural microbial population.

Gas analysis

Gas samples were taken from the packages and analyzed for contents of O_2 and CO_2 using O_2 and CO_2 analyzers (Model S-3A/I and Model CD-3A; Ametek, Pittsburgh, Pa., U.S.A.), and ethylene was measured with a gas chromatograph (Model AGC-211; Carle, Tulsa, Okla., U.S.A.) equipped with a flame ionization detector.

Quality analysis

Quality analyses included visual quality (VQ), aroma, translucency, texture, soluble solids content (SSC), and color. The sensory evaluations were conducted by five untrained, unaffiliated laboratory personnel using hedonic scales. Visual quality was scored with the widely used scale of 9 = excellent; 7 = good; 5 = fair; 3 = unsalable but edible; and 1 = inedible. Aroma was scored using a scale of 9 = strong, characteristic cantaloupe odor; 7 = pleasant, mild cantaloupe odor; 5 = bland, faint cantaloupe odor; 3 = mild sour or other off-odors; and 1 = distinct off-odor. For both scales, a score of 5 is generally considered in postharvest studies to be the threshold level of acceptability. Translucency was shown as the percentage of damaged cubes. Shear force was determined with a Kramer-Shear Cell attached to a Texture Test System (Food Technology Corp.; Rockville, Md, U.S.A.). Cubes in 100 g samples were placed in the cell randomly and the shear force was expressed in newtons (N). Color was based on CIE L*, a*, and b* values obtained with a white-tile calibrated chromameter (Model CR-300; Minolta, Japan) using five cubes per replication. Results were expressed as L*, chroma $C^* = [(a^*)^2 + (b^*)^2]^{°}$ and hue angle $h_{ab} = \tan^{-1}[(b^*)(a^*)^{-1}]$ (Minolta Corp. 1994).

Microbial analysis

The bacterial count was determined by incubating melon extracts on tryptic soy agar (TSA, Difco Laboratories, Detroit, Mich., U.S.A.). The yeast and mold

Table 1—Equilibrated ethylene concentrations in packages and ethylene production rates of fresh-cut cantaloupe cubes stored in 3 types of packaging at 2 temperatures over 3 trials

Trial	Ethylene concentration in package (µL L^{-1}) PFP[z]	nMAP[z]	fMAP[z]	Initial ethylene production rate at 5 °C (µL kg^{-1} h^{-1})
Trial 1	2 ± 1[y]	112 ± 15	29 ± 4	9.5 ± 1.4
Trial 2	1 ± 0	71 ± 16	21 ± 5	4.6 ± 0.8
Trial 3	1 ± 1	34 ± 8	8 ± 3	1.8 ± 0.5

[z] PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O_2 plus 10 kPa CO_2 prior to storage. Maximum concentrations and steady states for PFP were not maintained.
[y] Mean ± SD (n = 24 for ethylene concentrations and n = 6 for initial ethylene production rates).

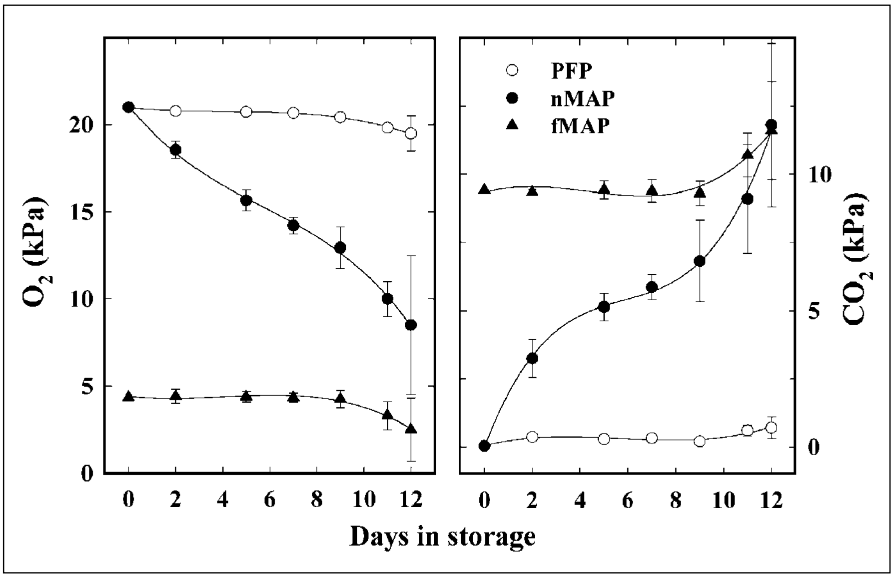

Figure 1—Oxygen and CO_2 concentrations in three types of packaging of fresh-cut cantaloupe cubes over 2 temperatures and 3 trials. PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O_2 plus 10 kPa CO_2 prior to storage. Vertical lines represent SD (n = 18). SD bars were not shown when masked by the symbol.

Table 2—Probability and significance of visual quality (VQ), aroma, translucency percent, L*, shear force, SSC, bacterial and yeast and mold populations of fresh-cut 'Athena' cantaloupe cubes stored in three types of packaging for 0, 2, 5, 7, 9, and 12 d over 2 temperatures and 3 trials

	DF	VQ	Aroma	Translucency	L*	Shear force	SSC population	Bacterial population	Yeast and mold population
Package (P)	2	0.0001**z	0.0001**	0.0001**	0.0001**	0.7835	0.9106	0.0011**	0.0001**
Day (D)	5	0.0001**	0.0001**	0.0001**	0.0060**	0.0001**	0.1471	0.0001**	0.0001**
P × D	17	0.0001**	0.0001**	0.0001**	0.0001**	0.9712	0.9992	0.0210*	0.0004**
Coef. Var.		6.15	3.69	119.64	4.50	16.60	7.74	11.15	20.8

[z]When next to data, * = $p < 0.05$; ** = $p < 0.01$ using Scheffe's multiple comparison test

count was determined by incubating extracts on potato dextrose agar (PDA) supplemented with 0.5 g L^{-1} chloramphenicol, both at 30 °C for 48 h as described elsewhere (Babic and Watada 1996).

Respiration and ethylene analyses

Respiration and ethylene production rates in CA and air were determined using a flow-through system for simulating the atmosphere in fMAP and PFP, respectively. A 300 g sample of cantaloupe cubes was placed on a plastic screen in a 2-liter glass jar. The jars were connected to a flow-through system (flow rate of 15 mL min^{-1}) of 4 kPa O_2 plus 10 kPa CO_2 or air. The O_2, CO_2, and ethylene levels were measured automatically every 8 h for 12 d. The respiration rate in nMAP and fMAP were calculated from the change of the gas concentration in the package and from film permeability.

Statistical analysis

Results presented were means for the experiment including 3 trials, 2 temperatures, and 3 packages with 3 replicates. PROC GLM of SAS Version 6.12 (SAS Institute Inc. 1989) was used for analysis of variance. The treatment means were separated at the 1 or 5% significance level by the Scheffe's multiple comparison test.

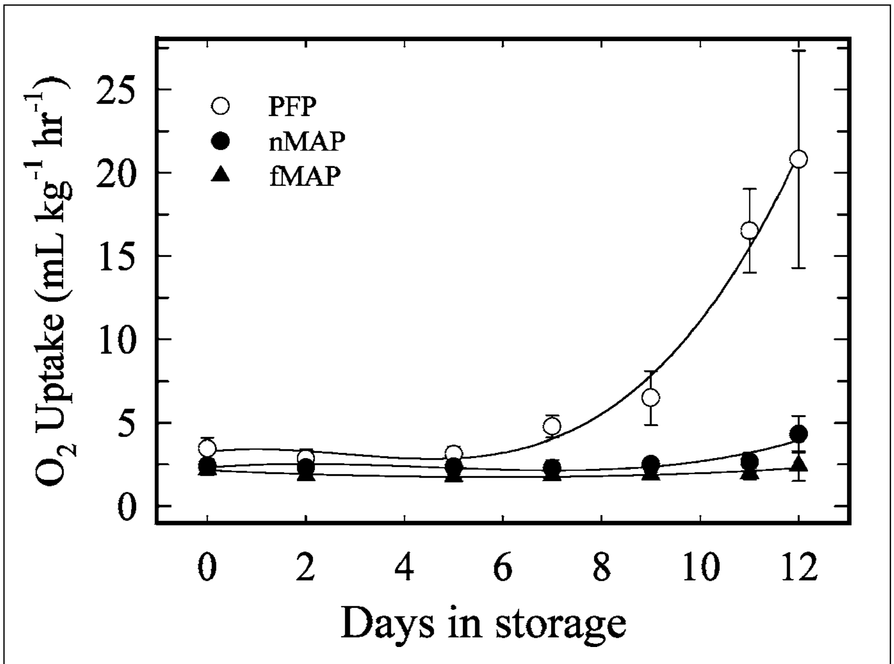

Figure 2—The average respiration rate based on O_2 uptake of fresh-cut cantaloupe cubes stored in 3 types of packaging at 5 °C over 3 trials. PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O_2 plus 10 kPa CO_2 prior to storage. Vertical lines represent SD (n = 18). SD bars were not shown when masked by the symbol.

Results and Discussion

Gas change in packages and respiration of fresh-cut cubes

The final gas level in a MAP system depends on film permeability and product respiration rate. Within PFP, the O_2 and CO_2 levels remained essentially the same as that in ambient air until d 9, and then changed by only 1 to 2 kPa during the next 3 d (Figure 1). In the air flow-through system, which was similar to the atmosphere within PFP, the average respiration rate based on O_2 uptake of cantaloupe cubes at 5 °C was stable during the first 5 d, then increased more than sixfold during the next 7 d (Figure 2). Within nMAP, the O_2 concentration decreased to 8 kPa while CO_2 increased to 12 kPa during 12 d at 5 °C, with neither gas reaching an equilibrium within the package (Figure 1). The average respiration rate within nMAP remained stable for about 9 d at 5 °C, or nearly twice as long as that in PFP. While the respiration rate increased about twofold between 9 and 12 d in nMAP, the rate at 12 d in nMAP was similar to that in PFP at d 7 and was only one-fifth that in PFP at d 12 (Figure 2). Within fMAP, the flushed gas mixture, 4 kPa O_2 plus 10 kPa CO_2, remained essentially unchanged during 12 d at 5 °C (Figure 1). The average respiration rate within fMAP also remained stable throughout the 12 d of storage at 5 °C (Figure 2). The increase in the average respiratory rate by d 7 and 12 in PFP and nMAP, respectively, was correlated with and was thought to have been caused by a general deterioration of the tissue. Ethylene levels increased during the first 5 d, then remained relatively stable. Ethylene accumulated in both nMAP and fMAP, but the ethylene level in fMAP was only about 1/4 of that in nMAP (Table 1). The atmospheres within the nMAP and fMAP did not have any adverse effect on the packaged cubes.

In the CA and air flow-through sys-

Table 3—Shelf life in d of fresh-cut cantaloupe cubes stored in 3 packaging at 2 temperatures over 3 trials

		PFP[z]		nMAP[z]		fMAP[z]	
Trial	Temperature	VQ[y]	Aroma	VQ	Aroma	VQ	Aroma
Trial 1	2.5-5 °C[x]	5.7 ± 1.2	7.0 ± 0.0	12.0 ± 0.0	10.0 ± 1.7	12.0 ± 0.0	11.0 ± 1.7
	5 °C	5.0 ± 0.0	6.3 ± 1.2	12.0 ± 0.0	9.0 ± 0.0	12.0 ± 0.0	9.0 ± 0.0
Trial 2	2.5-5 °C	7.0 ± 0.0	7.7 ± 1.2	10.0 ± 1.7	9.0 ± 0.0	10.0 ± 1.7	9.0 ± 0.0
	5 °C	7.0 ± 0.0	7.0 ± 0.0	9.0 ± 0.0	10.0 ± 1.7	10.0 ± 1.7	10.0 ± 1.7
Trial 3	2.5-5 °C	7.0 ± 0.0	9.0 ± 0.0	9.0 ± 0.0	9.0 ± 0.0	9.0 ± 0.0	12.0 ± 0.0
	5 °C	5.7 ± 1.2	10.0 ± 1.7	10.0 ± 1.7	9.0 ± 0.0	12.0 ± 0.0	12.0 ± 0.0

[z]PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O_2 plus 10 kPa CO_2 prior to storage.
[y]VQ = visual quality
[x]2 d at 2.5 °C and then transferred to 5 °C

tems, the corresponding average respiration rates were lower, and the respiratory increases delayed by 4 d when the fruit cubes were treated for 2 d at 2.5 °C and then transferred to 5 °C rather than being continuously treated at 5 °C (data not shown). In our MAP experiments, however, a 2-d treatment at 2.5 °C prior to 5 °C storage had little effect on the levels of gases in the packages when compared to those continuously treated at 5 °C. The ineffectiveness of the 2.5 °C treatment in MAP is due to the lowered temperature having a greater inhibitory effect on gas permeabilities of the film than on the average respiration rate of the cubes.

The initial ethylene production rate of the melon cubes for the 3 trials was variable (Table 1). However, the ethylene production rate of the cubes from all three trials decreased gradually during storage (data not shown). The declining ethylene production rates during experimentation indicate that the climacteric peak of ethylene production may have occurred before fresh-cut processing had began. The lower initial ethylene production of cubes in trial 3 indicated a more advanced stage of ripening of those samples compared to those in the other two trials.

Quality characteristics

Packaging and storage d significantly affected the two basic quality characteristics of visual quality and aroma (Table 2). The shelf life in PFP at 5 °C was 5 to 7 d (Table 3). Storing 2 d at 2.5 °C prior to 5 °C had little additional benefit for shelf life except in trial 3, in which it prolonged storage by 1 to 2 d more than those stored continuously at 5 °C (Table 3). Deterioration was primarily due to the development of translucency—that is, lower scores of visual quality. The percent translucency of cubes in PFP was greater than 30% after d 7 (Figure 3), indicating that the produce was in an advanced stage of senescence. Translucency greater than 20% may be considered the limit of salable quality. O'Connor-Shaw and others (1996) indicated that translucency occurred in all treatments not containing CO_2 and in some treatments having greater than 15 kPa O_2.

Both nMAP and fMAP maintained the shelf life of cubes for 9 to 12 d (Table 3), and lowered translucency (Figure 3). However, translucency was detected 2 d earlier and was two- to fivefold higher between 9 and 12 d in nMAP than in fMAP, which indicated that melon cubes in nMAP were senescing faster than those in fMAP. A faint off-odor occurred by d 12 in all samples except the cubes in fMAP in trial 3, which retained a mild melon aroma. The development of off-odor was associated with the presence of fungi on the surface of the cubes, not to anaerobic respiration of the cube tissue.

A high lightness (Figure 3) and bright orange color were observed on good, high quality cube surfaces. The initial L* value, as lightness, was 59. The value in fMAP gradually increased, while it remained essentially unchanged in nMAP. The value in PFP decreased slowly during the first 5 d, then more rapidly over the next 7 d. The chroma (C*), brightness of the cube surface color, was initially 34 with a hue angle (h_{ab}) of 72°. Due to increasing translucency, C* showed the same pattern of change as for L* in all treatments, but h_{ab} remained constant

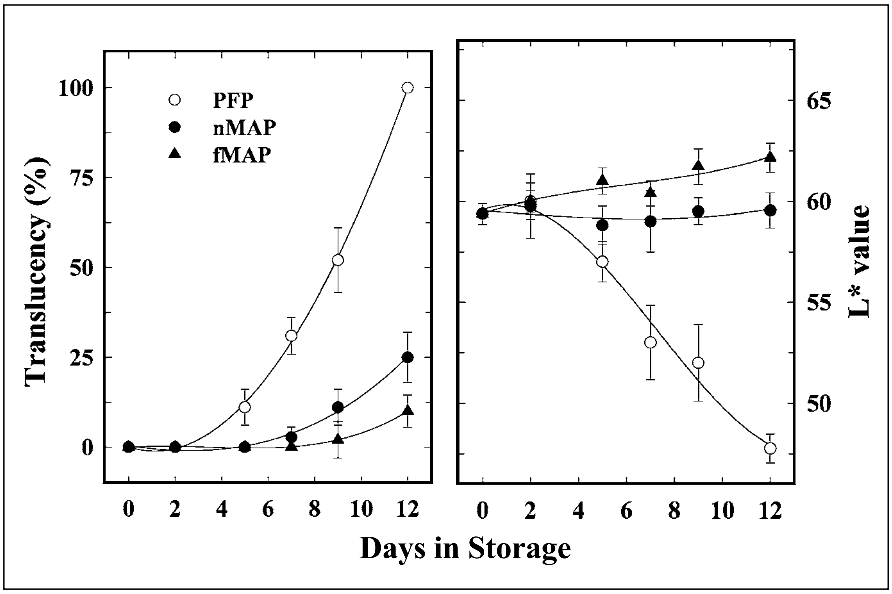

Figure 3—Translucency percent and L* values of fresh-cut cantaloupe cubes stored in 3 types of packaging over 2 temperatures and 3 trials. PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O_2 plus 10 kPa CO_2 prior to storage. Vertical lines represent SD (n = 18). SD bars were not shown when masked by the symbol.

(data not shown).

The firmness of the cubes was significantly different among trials (data not shown), but was not different among package types (Table 2). The initial shear force was about 700 N for trials 1 and 2, and 500 N for trial 3 where the fruits were shipped to market for two d before laboratory analyses. Samples from trials 1 and 2 that had a relatively high initial shear force softened faster than those of trial 3 having a lower initial firmness. The average shear force loss from d 0 to d 9 of cubes prepared from field- and market-derived fruit was 34% and 10%, respectively. However, no difference was shown among package types and storage temperatures (Table 2). The soluble solids content (SSC) was about 9.5% in samples from all 3 trials and did not change during 12 d of storage in all treatments. The SSC was lower than expected, and probably was due to the influx of sanitizer into the cubes during cube dipping treatments—that is, the fruit cubes gained weight during the dipping treatments.

Microbial populations

Initial populations of bacteria (TSA) were about log 3.2 CFU g^{-1}, while those for yeasts and molds (PDA) were less than log 1.9 CFU g^{-1}. Microbial populations on both TSA and PDA increased in all samples as storage time increased, regardless of the treatment (Figure 4). However, by d 5, microbial populations were higher for PFP than for nMAP or fMAP. The total microbial population was generally between 0.2 (-35% reduction) and 0.5 (-70% reduction) log units lower in fMAP than in nMAP (Figure 4). Bacterial counts ranged from log 3 to log 10 CFU g^{-1}. The quality of the cubes in nMAP and fMAP on d 9 of storage was acceptable, even though they had bacterial counts of log 8 CFU g^{-1}. Yeasts and molds were less numerous than bacteria, which is the same pattern as that found on other fresh-cut produce (Nguyen-The and Cartin 1994). The benefit of elevated carbon dioxide in modified atmosphere is due to its fungi- and bacterio-static characteristics against many spoilage organisms that can grow at refrigerated temperatures (Enfors and Molin 1978). Carbon dioxide also increased the lag phase of growth curves for several spoilage organisms (Coyne 1933). Low oxygen in MAP generally inhibits the growth of aerobic microorganisms.

Conclusions

NATURALLY MODIFIED ATMOSPHERE packaging (nMAP) was beneficial for fresh-cut 'Athena' cantaloupe cubes, retaining salable quality for 9 d at 5 °C. Rapidly flushed modified atmosphere packaging (fMAP, 4 kPa O_2 plus10 kPa CO_2) maintained quality better than pMAP; that is, better color retention and reduced translucency, respiration rate, and microbial populations. The question remains whether or not the improved quality of fresh-cut melon in fMAP relative to nMAP is worth the added cost of flushing the package atmosphere. Salability was limited mainly by the development of translucency and/or off-odor.

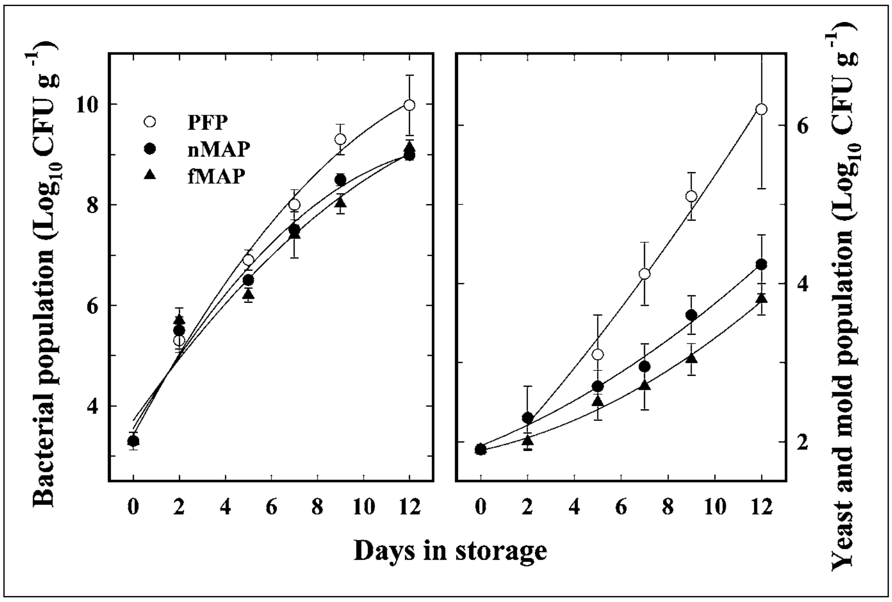

Figure 4—Bacterial, yeast, and mold populations of fresh-cut cantaloupe cubes stored in three types of packaging over 2 temperatures and 3 trials. PFP = packages had film overlap perforated to have 10 1.5-mm holes; nMAP = packages in which a modified atmosphere was formed naturally; fMAP = packages in which the internal atmosphere was flushed with a gas mixture of 4 kPa O_2 plus 10 kPa CO_2 prior to storage. Vertical lines represent SD (n = 18). SD bars were not shown when masked by the symbol.

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MS 20000413

This work was funded by the U.S. Dept. of Agriculture, Agricultural Research Service. We gratefully acknowledge Willard Douglas for excellent technical assistance. Mention of brand or firm names does not constitute an endorsement by the U.S. Dept. of Agriculture over others of a similar nature not mentioned.

Authors Bai, Saftner, and Watada are affiliated with the Produce Quality and Safety Laboratory, Beltsville Agricultural Research Center, Agricultural Research Service, U.S. Dept. of Agriculture, Beltsville, MD 20705-2350. Author Lee is with the Nutrition and Food Science Program, Dept. of Biological and Environmental Sciences, Univ. of the District of Columbia, Washington, D.C. Direct inquiries to author Saftner (E-mail: saftnerr@ba.ars.usda.gov).